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APPLICATION OF THE METROLOGICAL SPM FOR LONG DISTANCE MEASUREMENTS

Nataliya Vorbringer-Dorozhovets, Roland Füßl, Eberhard Manske

Ilmenau University of Technology, Faculty of Mechanical Engineering, Institute of Process Measurement and Sensor Technology, PO Box 100 565, D-98684 Ilmenau, Germany

ABSTRACT

Current trends in micro-, nanotechnology and precision engineering demand scanning probe microscopy (SPM) measurement at ever larger distances as well as with ever higher resolutions and accuracies. The nanopositioning and nanomeasuring (NPM) machine developed at the Ilmenau University of Technology with a measuring range of 25 mm × 25 mm × 5 mm and subnanometre resolution constitute an excellent scanning stage for such SPM measurements. This research deals with the challenges of scans over a range of several millimeters performed by the NPM machine in combination with the metrological SPM-head. Examples for such long distance measurements are topography scans over several millimeters for investigation of structure transformation or for determination of the nanoscale roughness of surface profile. Whereupon the tip size of the cantilever and its alteration affect the measurement result. Another challenge is the pitch determination of glass scale over a range of 20 mm. Usually the average pitch value can be traceable measured with very high accuracy using optical diffractometry. Besides the mean pitch, the SPM technique allows the determination of local pitch variation and uniformity. The NPM machine and metrological SPM-head were applied before for measurement of pitch standards over a range of 1 mm where excellent results are achieved.

Index Terms - nanopositioning and nanomeasuring machine, metrological scanning probe microscope, SPM, AFM, long distance measurements

1. INTRODUCTION

This paper deals with the large distance scanning probe microscopy (SPM). Generally an SPM is used for investigation, analysis and imaging of surface properties with nanometer resolution. Usually the scanning motion in SPM is provided by piezoelectric actuators and the scanning range is limited to a few hundreds micrometer [1, 2].

Traceable high-precision long-range SPM measurements are important for the semiconductor industry, precision engineering and other key technologies. As example, the SPM with good metrological characteristics (metrological SPM) can be used in National Measurement Institutes (NMIs) for calibration of standards. Particularly long distance scans (more than 1 mm) are important for attainment better statistical result of the mean pitch of the lateral standards [3]. Furthermore long-range SPM can be applied for roughness measurement [4].

The metrological SPM-head was already detailed explained in several publications [5, 6 and 7]. The main feature of the SPM-head is the special developed metrological deflection detection system that combines a homodyne interferometer and optical lever-detection system [5]. The metrological SPM-head is used as the probe system for nanopositioning and nanomeasuring (NPM) machine [8] (cf. fig. 1) and therefore long distance measurements over a range of 25 mm × 25 mm with a resolution of 0.1 nm are feasible.

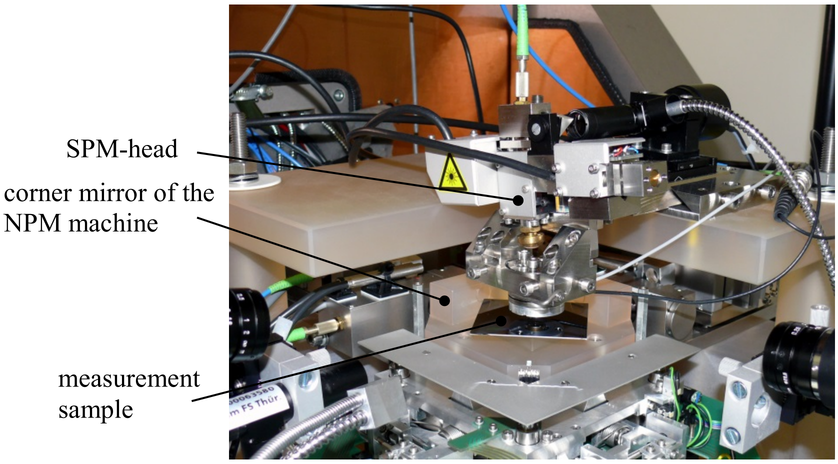

Figure 1. Metrological SPM-head as the probe system of the NPM machine.

2. APPLICATION FOR DETERMINATION OF THE NANOSCALE ROUGHNESS OF SURFACE PROFILE

Traditionally for surface roughness measurement stylus profilometry is used. The measurement principle of the profilometer is similar to SPM. The lateral resolution of this method depends on the stylus tip radius (amounts typically 2 up to 5 µm) of the profilometer. Therefore the SPM allows better lateral resolution due to much smaller tip radius of the cantilever (amounts typically 10 up to 15 nm). The probing forces in SPM are in nanonewton range; thereby non-destructive investigations of soft surfaces are possible. The standard for assessment of surface texture ISO 4288 (1996) [9] requires defined scan distances. These distances (minimum 0.4 mm) are to long for common commercial AFMs but can be scanned by the NPM machine.

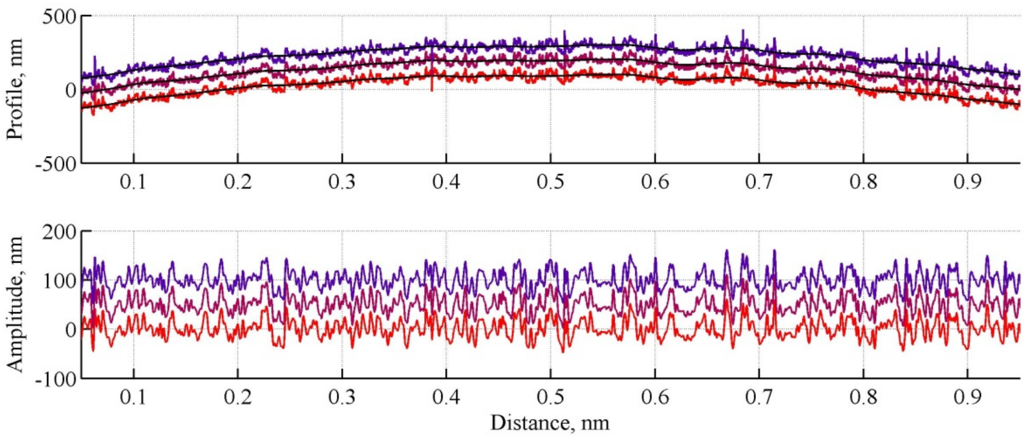

Figure 2. Measured detrended profiles of silicone optic cable and its roughness profiles after filtering.

In this paper we will demonstrate the investigations for determination of roughness of silicone optic cable. Ten 1 mm long profiles were side by side scanned along the cable in intermittent mode of operation. The spacing between profiles as well as measuring point distance is 2 nm. Measured profiles were filtered using the Gaussian filter [10] at the selected cutoff wavelength λ_c = 0.08 mm and the short wavelength cutoff λ_s = 2.5 µm accordingly to ISO 3274 [11]. For this filter parameter the root mean square and average roughness were calculated: R_q = 18.9 nm and R_a = 15.3 nm. Figure 2 shows (exemplarily) three measured detrended profiles and its roughness after filtering. The curves are displaced for better representation.

3. PITCH DETERMINATION OVER A LARGE RANGE

Next applications of the metrological SPM are long distance measurements of the glass scale with the nominal pitch of 8 µm. The long scanning range is important for measurements over a large number of pitches in order to obtain a better result for the mean pitch.
Three 20 mm long profiles were measured with the measuring point distance of 20 nm also in intermittent mode of operation. The distance between this profiles amounts respectively 1 mm. The scan was repeated 10 times. Figure 3(a) shows detail from one repeated measured profile. The mean pitch was obtained using the Fourier transform method (FFT) [3, 6]. The values for all measured profiles are given in figure 3(b). The maximal difference between pitches, determined from different profiles without one scan, amounts to 74 pm. The mean pitch can be calculated for each scan. The result of the mean pitch is the average obtained over all scans: 8,000527 µm. Then the repeatability of the pitch determination can be represented as the standard deviation (std) obtained over all 10 scans. In this case the std is 11 pm.

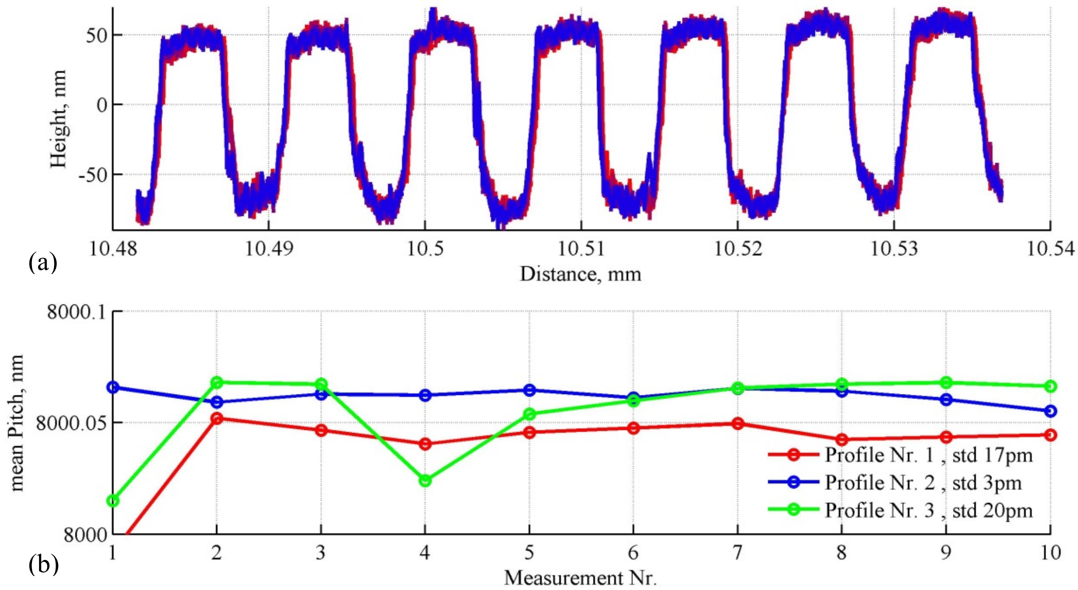

Figure 3. Glass scale: (a) Section from measured profile, (b) Measurement results.

4. FURTHER MEASUREMENTS APPLICATIONS

Finally we will show a topography scan over 5 mm. Such measurement is intended to support the investigation of structure transformation. 1.5 µm × 5 mm scan was performed with the measuring point distance of 5 nm. The wear of the cantilever tip significantly influences the topography measurement and therewith the changing of structure. Therefore the length along the scan axis was set to 5 mm. 300 structure profiles were scanned in intermittent mode of operation. Main challenges are the handling and processing of an amount of data: 300 million measured points with memory capacity of 40 GB. No commercial software for SPM image processing can handle such data volume. Some sections from the scan are shown in figure 4.

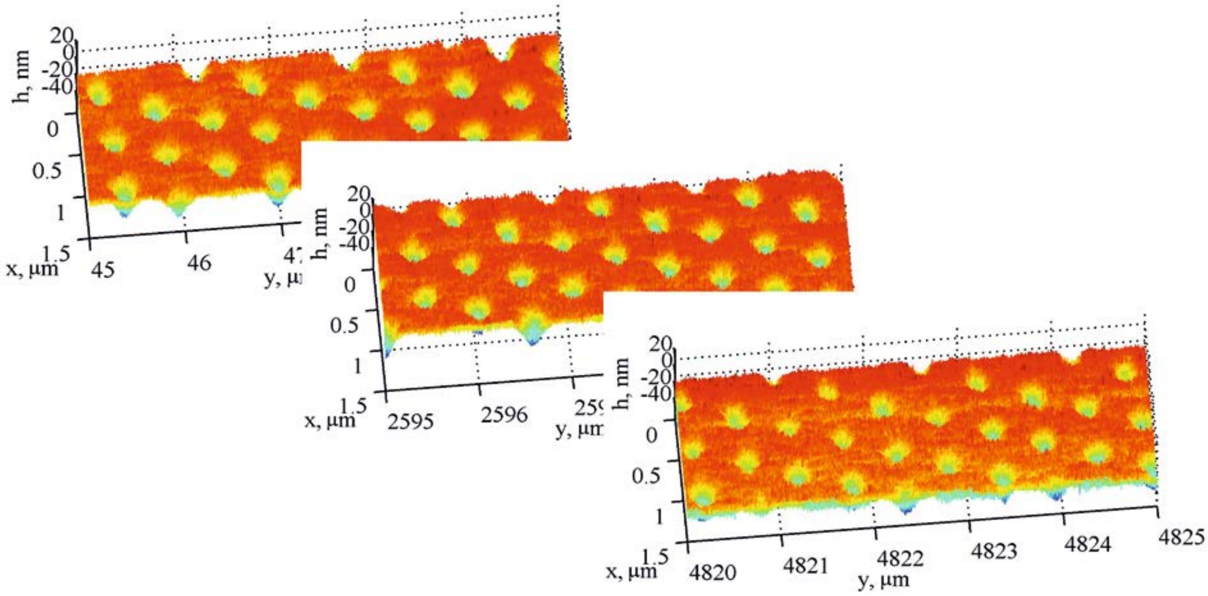

Figure 4. Three sections from the scanned structure.

5. CONCLUSIONS AND OUTLOOK

In this paper we gave examples of long distance measurements performed by the metrological SPM-head and the NPM machine. As example very good results are achieved for measurements of glass scales.

The wear of the cantilever tip can influence the measurement results. Therefore this effect (of the tip wear) is very important in particular for long distance measurements. Next steps are the investigation of the wearing of the tip.

6. ACKNOWLEDGMENTS

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CONTACTS

Dipl.-Ing. N. Vorbringer-Dorozhovets nataliya.vorbringer-dorozhovets@tu-ilmenau.de
Dr.-Ing. habil. R. Füßl roland.fuessl@tu-ilmenau.de
Prof. Dr.-Ing. habil. E. Manske eberhard.manske@tu-ilmenau.de